This Jupyter Notebook script is part of the Mistry & Gasparrani (2024) paper "Real-time forecast of temperature-related excess mortality at small-area level: towards an operational framework" published in Environmental Research: Health. The code documented here demonstrates how to access the high-resolution (0.25 deg gridded) temperature forecast from the ECMWF using the Python open-data package.

Note: The gridded temperature data used in the study was at 0.4 deg resolution. ECMWF has since updated their data policy and made even higher resolution data (0.25 deg) publicly available. Nonetheless, the aggregation of the gridded data to LSOA boundaries (in England & Wales; see paper) is done in R for further analyses. These LSOA-level temperature series are provided in the Github repo (see Mistry & Gasparrini 2024 for further details).

The demo notebook here shows how to download the newer 0.25 deg forecast for the same days (17-22 July) but for 2024 instead of 2022 (How to access the recent available forecast is also demonstrated). Since the ECMWF has archieved the earlier 0.4 deg forecast data, it is no longer possible to download the same (i.e., forecast data prior approx Jan 2024 cannot be accessed using this open-data framework).

Link the ECMWF-Opendata package and open-data forecast repository

https://github.com/ecmwf/ecmwf-opendata

https://www.ecmwf.int/en/forecasts/datasets/open-data

Install required python packages

```
'''
!pip install ecmwf-opendata
!pip install ecmwf-data ecmwf-api-client magpye
!pip install cfgrib
!pip install --upgrade google-api-python-client
!pip install cartopy        # Only for plotting. Use below if pip
doesn't work
!conda install -c conda-forge cartopy -y
!pip install rasterio rioxarray  # Only for plotting
'''

"\n!pip install ecmwf-opendata\n!pip install ecmwf-data ecmwf-api-
client magpye\n!pip install cfgrib\n!pip install --upgrade google-api-
python-client\n!pip install cartopy        # Only for plotting. Use
below if pip doesn't work\n!conda install -c conda-forge cartopy -y  \
n!pip install rasterio rioxarray  # Only for plotting\n"

import ecmwf.data as ecdata
from magpye import GeoMap
from ecmwfapi import *
import requests
from ecmwf.opendata import Client
import xarray as xr
import pandas as pd
import numpy as np
import cfgrib

## Only for Plotting
import matplotlib.pyplot as plt
import cartopy.crs as ccrs
import cartopy
import rasterio
import rioxarray
```

Check the latest available forecast

```
client = Client(source="ecmwf")

result=client.retrieve(
   # time=0,
    stream="oper",
```

```
    type="fc",
    step=24,
    param="2t",
    target="tas.grib2",
)

print(result.datetime)
```

```
set() ['fc']
set() ['24']
set() ['100u', '100v', '10u', '10v', '2d', '2t', 'asn', 'cape', 'd',
'gh', 'lsm', 'msl', 'q', 'r', 'ro', 'skt', 'sp', 'ssr', 'ssrd', 'st',
'stl2', 'stl3', 'stl4', 'str', 'strd', 'swvl1', 'swvl2', 'swvl3',
'swvl4', 't', 'tcwv', 'tp', 'ttr', 'u', 'v', 'vo', 'w']

{"model_id":"","version_major":2,"version_minor":0}

2024-07-18 00:00:00
```

We now download the 3hrly data starting from 17July2024 (Note: 03h and ending on 22July2024 at 24h (i.e., total 6 days). Note that we select the forecast issued at 00h UTC on the 17July2024. To do so, we create a list of 3 hourly sequence for total 6 days starting from 03h. Since each day will have 8 3hrly timesteps (03-24h), 6 days would require the sequence to end at 144

One can similarly change the dates to download the forecast for May 2024

```
hour_steps = [*range(3, 147, 3)]
print(hour_steps)
```

```
[3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 33, 36, 39, 42, 45, 48, 51, 54,
57, 60, 63, 66, 69, 72, 75, 78, 81, 84, 87, 90, 93, 96, 99, 102, 105,
108, 111, 114, 117, 120, 123, 126, 129, 132, 135, 138, 141, 144]
```

The data (grib2 file format) will download in the current work directory

```
client = Client(source="ecmwf")

client.retrieve(
    time=0,
    date='2024-07-17',
    stream="oper",
    type="fc",
    step = hour_steps,
    param="2t",
    target="tas_3hrly_17July_22July_2024.grib2",
)
```

```
set() ['fc']
set() ['102', '105', '108', '111', '114', '117', '12', '120', '123',
'126', '129', '132', '135', '138', '141', '144', '15', '18', '21',
'24', '27', '3', '30', '33', '36', '39', '42', '45', '48', '51', '54',
'57', '6', '60', '63', '66', '69', '72', '75', '78', '81', '84', '87',
'9', '90', '93', '96', '99']
set() ['100u', '100v', '10u', '10v', '2d', '2t', 'asn', 'cape', 'd',
'gh', 'lsm', 'msl', 'q', 'r', 'ro', 'skt', 'sp', 'ssr', 'ssrd', 'st',
'stl2', 'stl3', 'stl4', 'str', 'strd', 'swvl1', 'swvl2', 'swvl3',
'swvl4', 't', 'tcwv', 'tp', 'ttr', 'u', 'v', 'vo', 'w']

{"model_id":"","version_major":2,"version_minor":0}

<ecmwf.opendata.client.Result at 0x192a30810>
```

Read the grib2 file

```
data = ecdata.read('tas_3hrly_17July_22July_2024.grib2')
data.describe()

<IPython.core.display.HTML object>

data.describe('2t')

<IPython.core.display.HTML object>
```

The first 8 steps are lead times 03, 06, 09, 12, 15, 18, 21 and 24 hr forecasts for 17 July 2022, python index [0:8].

Recall that in python the last index is not included and so it is 8 and not 7

```
data.ls()

        centre shortName    typeOfLevel      level  dataDate  dataTime

Message

0        ecmf      2t     heightAboveGround    2    20240717      0
\
1        ecmf      2t     heightAboveGround    2    20240717      0

2        ecmf      2t     heightAboveGround    2    20240717      0

3        ecmf      2t     heightAboveGround    2    20240717      0

4        ecmf      2t     heightAboveGround    2    20240717      0

5        ecmf      2t     heightAboveGround    2    20240717      0

6        ecmf      2t     heightAboveGround    2    20240717      0
```

7	ecmf	2t	heightAboveGround	2	20240717	0
8	ecmf	2t	heightAboveGround	2	20240717	0
9	ecmf	2t	heightAboveGround	2	20240717	0
10	ecmf	2t	heightAboveGround	2	20240717	0
11	ecmf	2t	heightAboveGround	2	20240717	0
12	ecmf	2t	heightAboveGround	2	20240717	0
13	ecmf	2t	heightAboveGround	2	20240717	0
14	ecmf	2t	heightAboveGround	2	20240717	0
15	ecmf	2t	heightAboveGround	2	20240717	0
16	ecmf	2t	heightAboveGround	2	20240717	0
17	ecmf	2t	heightAboveGround	2	20240717	0
18	ecmf	2t	heightAboveGround	2	20240717	0
19	ecmf	2t	heightAboveGround	2	20240717	0
20	ecmf	2t	heightAboveGround	2	20240717	0
21	ecmf	2t	heightAboveGround	2	20240717	0
22	ecmf	2t	heightAboveGround	2	20240717	0
23	ecmf	2t	heightAboveGround	2	20240717	0
24	ecmf	2t	heightAboveGround	2	20240717	0
25	ecmf	2t	heightAboveGround	2	20240717	0
26	ecmf	2t	heightAboveGround	2	20240717	0
27	ecmf	2t	heightAboveGround	2	20240717	0
28	ecmf	2t	heightAboveGround	2	20240717	0
29	ecmf	2t	heightAboveGround	2	20240717	0
30	ecmf	2t	heightAboveGround	2	20240717	0
31	ecmf	2t	heightAboveGround	2	20240717	0
32	ecmf	2t	heightAboveGround	2	20240717	0

```
33       ecmf      2t     heightAboveGround    2    20240717       0

34       ecmf      2t     heightAboveGround    2    20240717       0

35       ecmf      2t     heightAboveGround    2    20240717       0

36       ecmf      2t     heightAboveGround    2    20240717       0

37       ecmf      2t     heightAboveGround    2    20240717       0

38       ecmf      2t     heightAboveGround    2    20240717       0

39       ecmf      2t     heightAboveGround    2    20240717       0

40       ecmf      2t     heightAboveGround    2    20240717       0

41       ecmf      2t     heightAboveGround    2    20240717       0

42       ecmf      2t     heightAboveGround    2    20240717       0

43       ecmf      2t     heightAboveGround    2    20240717       0

44       ecmf      2t     heightAboveGround    2    20240717       0

45       ecmf      2t     heightAboveGround    2    20240717       0

46       ecmf      2t     heightAboveGround    2    20240717       0

47       ecmf      2t     heightAboveGround    2    20240717       0


        stepRange dataType number   gridType
Message
0               3       fc     None   regular_ll
1               6       fc     None   regular_ll
2               9       fc     None   regular_ll
3              12       fc     None   regular_ll
4              15       fc     None   regular_ll
5              18       fc     None   regular_ll
6              21       fc     None   regular_ll
7              24       fc     None   regular_ll
8              27       fc     None   regular_ll
9              30       fc     None   regular_ll
10             33       fc     None   regular_ll
11             36       fc     None   regular_ll
12             39       fc     None   regular_ll
13             42       fc     None   regular_ll
14             45       fc     None   regular_ll
15             48       fc     None   regular_ll
16             51       fc     None   regular_ll
17             54       fc     None   regular_ll
```

```
18            57      fc     None   regular_ll
19            60      fc     None   regular_ll
20            63      fc     None   regular_ll
21            66      fc     None   regular_ll
22            69      fc     None   regular_ll
23            72      fc     None   regular_ll
24            75      fc     None   regular_ll
25            78      fc     None   regular_ll
26            81      fc     None   regular_ll
27            84      fc     None   regular_ll
28            87      fc     None   regular_ll
29            90      fc     None   regular_ll
30            93      fc     None   regular_ll
31            96      fc     None   regular_ll
32            99      fc     None   regular_ll
33           102      fc     None   regular_ll
34           105      fc     None   regular_ll
35           108      fc     None   regular_ll
36           111      fc     None   regular_ll
37           114      fc     None   regular_ll
38           117      fc     None   regular_ll
39           120      fc     None   regular_ll
40           123      fc     None   regular_ll
41           126      fc     None   regular_ll
42           129      fc     None   regular_ll
43           132      fc     None   regular_ll
44           135      fc     None   regular_ll
45           138      fc     None   regular_ll
46           141      fc     None   regular_ll
47           144      fc     None   regular_ll
```

Convert the temp from Kelvin to deg C

```
data = data - 273.15
```

Now we read the same data saved as grib2 file using xarray so that summary statisics, plotting and conversion to netcdf becomes easier

```
ds = xr.load_dataset('tas_3hrly_17July_22July_2024.grib2',
engine="cfgrib")
ds
```

```
<xarray.Dataset>
Dimensions:            (step: 48, latitude: 721, longitude: 1440)
Coordinates:
    time               datetime64[ns] 2024-07-17
  * step               (step) timedelta64[ns] 0 days 03:00:00 ... 6
days 00:0...
    heightAboveGround  float64 2.0
  * latitude           (latitude) float64 90.0 89.75 89.5 ... -89.5 -
```

```
89.75 -90.0
  * longitude          (longitude) float64 -180.0 -179.8 -179.5 ...
179.5 179.8
    valid_time         (step) datetime64[ns] 2024-07-17T03:00:00 ...
2024-07-23
Data variables:
    t2m                (step, latitude, longitude) float32 273.7 273.7
... 235.9
Attributes:
    GRIB_edition:            2
    GRIB_centre:             ecmf
    GRIB_centreDescription:  European Centre for Medium-Range Weather
Forecasts
    GRIB_subCentre:          0
    Conventions:             CF-1.7
    institution:             European Centre for Medium-Range Weather
Forecasts
    history:                 2024-07-18T11:37 GRIB to CDM+CF via
cfgrib-0.9.1...
```

Drop 'time' 'valid_time" and 'heightAboveGround' coordinates as they are not required. Then rename the dimension 'step' to 'time'

```
del ds["time"]
del ds["valid_time"]
del ds["heightAboveGround"]
ds
```

```
<xarray.Dataset>
Dimensions:    (step: 48, latitude: 721, longitude: 1440)
Coordinates:
  * step       (step) timedelta64[ns] 0 days 03:00:00 ... 6 days
00:00:00
  * latitude   (latitude) float64 90.0 89.75 89.5 89.25 ... -89.5 -
89.75 -90.0
  * longitude  (longitude) float64 -180.0 -179.8 -179.5 ... 179.2
179.5 179.8
Data variables:
    t2m        (step, latitude, longitude) float32 273.7 273.7 ...
235.9 235.9
Attributes:
    GRIB_edition:            2
    GRIB_centre:             ecmf
    GRIB_centreDescription:  European Centre for Medium-Range Weather
Forecasts
    GRIB_subCentre:          0
    Conventions:             CF-1.7
    institution:             European Centre for Medium-Range Weather
Forecasts
```

```
    history:                  2024-07-18T11:37 GRIB to CDM+CF via
cfgrib-0.9.1...

ds=ds.rename({'step': 'time'})
ds.time

<xarray.DataArray 'time' (time: 48)>
array([ 10800000000000,  21600000000000,  32400000000000,
43200000000000,
        54000000000000,  64800000000000,  75600000000000,
86400000000000,
        97200000000000, 108000000000000, 118800000000000,
129600000000000,
       140400000000000, 151200000000000, 162000000000000,
172800000000000,
       183600000000000, 194400000000000, 205200000000000,
216000000000000,
       226800000000000, 237600000000000, 248400000000000,
259200000000000,
       270000000000000, 280800000000000, 291600000000000,
302400000000000,
       313200000000000, 324000000000000, 334800000000000,
345600000000000,
       356400000000000, 367200000000000, 378000000000000,
388800000000000,
       399600000000000, 410400000000000, 421200000000000,
432000000000000,
       442800000000000, 453600000000000, 464400000000000,
475200000000000,
       486000000000000, 496800000000000, 507600000000000,
518400000000000],
      dtype='timedelta64[ns]')
Coordinates:
  * time     (time) timedelta64[ns] 0 days 03:00:00 ... 6 days
00:00:00
Attributes:
    long_name:      time since forecast_reference_time
    standard_name:  forecast_period
```

Format the time axis

```
ds['time'] = pd.date_range("2024-07-17T03:00:00.000000000",
periods=48, freq='3H')
ds.time

<xarray.DataArray 'time' (time: 48)>
array(['2024-07-17T03:00:00.000000000', '2024-07-
17T06:00:00.000000000',
       '2024-07-17T09:00:00.000000000', '2024-07-
17T12:00:00.000000000',
```

```
       '2024-07-17T15:00:00.000000000', '2024-07-
17T18:00:00.000000000',
       '2024-07-17T21:00:00.000000000', '2024-07-
18T00:00:00.000000000',
       '2024-07-18T03:00:00.000000000', '2024-07-
18T06:00:00.000000000',
       '2024-07-18T09:00:00.000000000', '2024-07-
18T12:00:00.000000000',
       '2024-07-18T15:00:00.000000000', '2024-07-
18T18:00:00.000000000',
       '2024-07-18T21:00:00.000000000', '2024-07-
19T00:00:00.000000000',
       '2024-07-19T03:00:00.000000000', '2024-07-
19T06:00:00.000000000',
       '2024-07-19T09:00:00.000000000', '2024-07-
19T12:00:00.000000000',
       '2024-07-19T15:00:00.000000000', '2024-07-
19T18:00:00.000000000',
       '2024-07-19T21:00:00.000000000', '2024-07-
20T00:00:00.000000000',
       '2024-07-20T03:00:00.000000000', '2024-07-
20T06:00:00.000000000',
       '2024-07-20T09:00:00.000000000', '2024-07-
20T12:00:00.000000000',
       '2024-07-20T15:00:00.000000000', '2024-07-
20T18:00:00.000000000',
       '2024-07-20T21:00:00.000000000', '2024-07-
21T00:00:00.000000000',
       '2024-07-21T03:00:00.000000000', '2024-07-
21T06:00:00.000000000',
       '2024-07-21T09:00:00.000000000', '2024-07-
21T12:00:00.000000000',
       '2024-07-21T15:00:00.000000000', '2024-07-
21T18:00:00.000000000',
       '2024-07-21T21:00:00.000000000', '2024-07-
22T00:00:00.000000000',
       '2024-07-22T03:00:00.000000000', '2024-07-
22T06:00:00.000000000',
       '2024-07-22T09:00:00.000000000', '2024-07-
22T12:00:00.000000000',
       '2024-07-22T15:00:00.000000000', '2024-07-
22T18:00:00.000000000',
       '2024-07-22T21:00:00.000000000', '2024-07-
23T00:00:00.000000000'],
      dtype='datetime64[ns]')
Coordinates:
  * time     (time) datetime64[ns] 2024-07-17T03:00:00 ... 2024-07-23
```

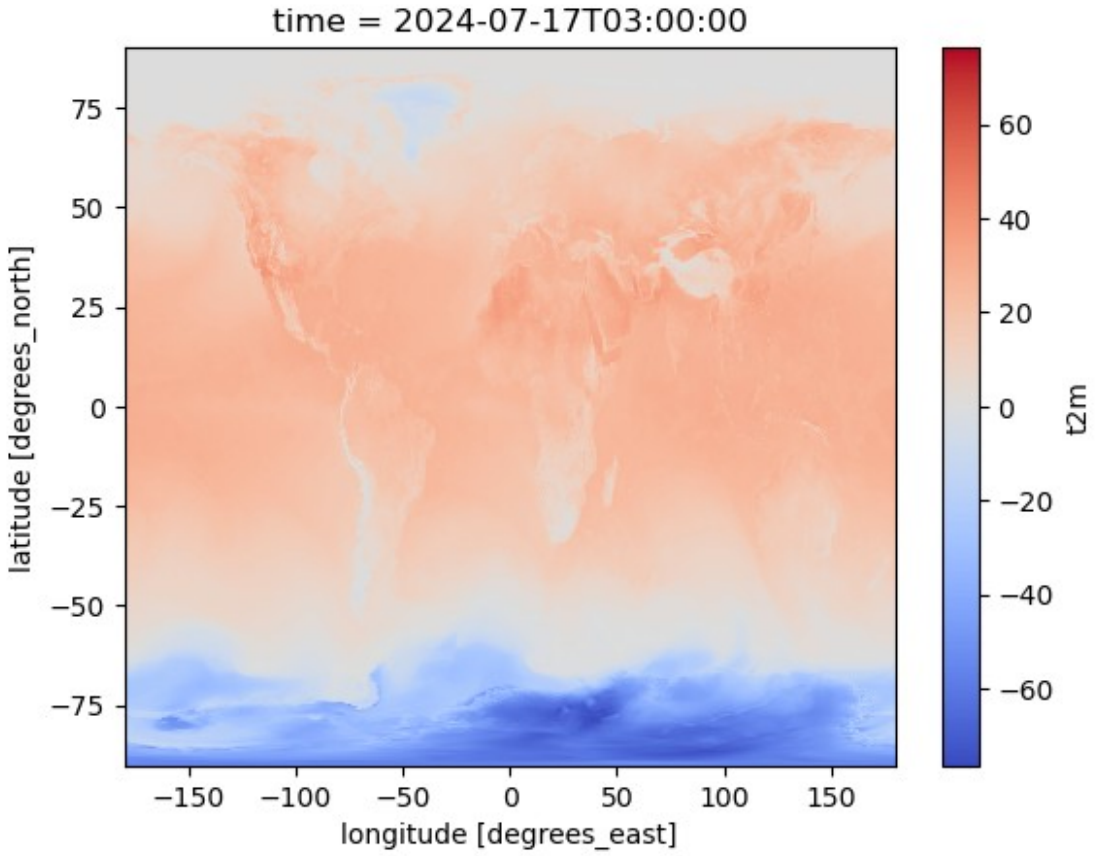
Convert to deg C. Note, earlier we converted the 'data' object to deg C, but the actual grib2 file that was written was still in deg K. Save the output as a netcdf (3hrly temperature)

```
ds['t2m'] = ds['t2m'] - 273.15
ds.to_netcdf(path="tas_3hrly_17July_22July_2024.nc", mode='w')
```

Some plots for demo

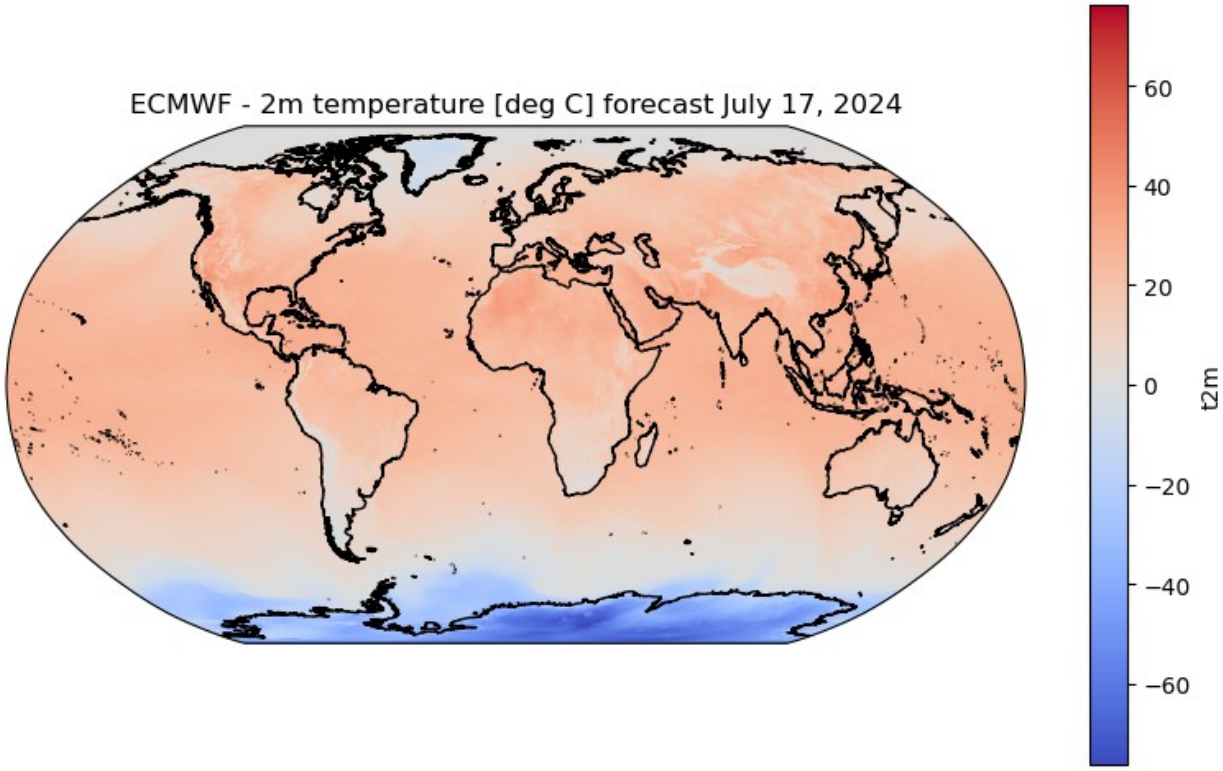
```
# Plot temperature at 03h on 17-July-2024
ds.t2m[0].plot(cmap=plt.cm.coolwarm)
```

```
<matplotlib.collections.QuadMesh at 0x198c2bbd0>
```




```
fig = plt.figure(figsize=(10, 10))
ax = plt.axes(projection=ccrs.Robinson())
ax.coastlines(resolution="10m")
plot = ds.t2m[0].plot(
    cmap=plt.cm.coolwarm, transform=ccrs.PlateCarree(),
cbar_kwargs={"shrink": 0.6}
)
plt.title("ECMWF - 2m temperature [deg C] forecast July 17, 2024")
```

```
Text(0.5, 1.0, 'ECMWF - 2m temperature [deg C] forecast July 17, 2024')
```



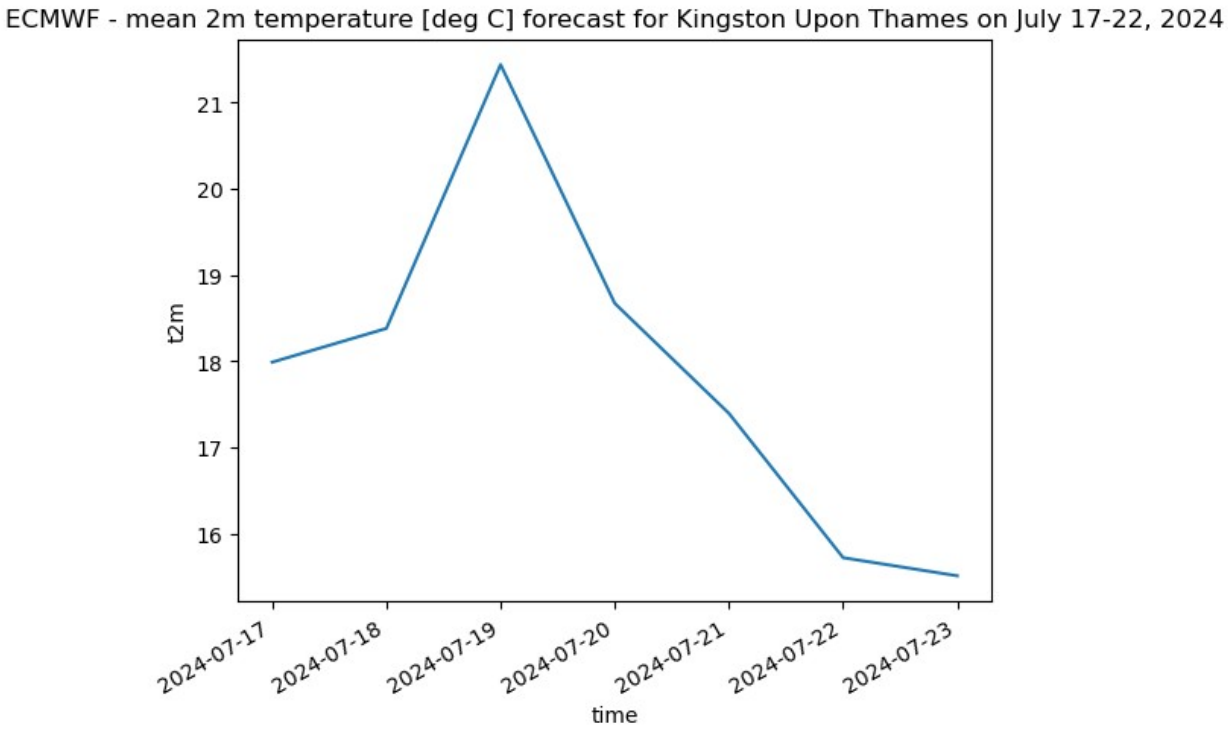
Compute gridded daily averages from 3-hourly temperature. This daily Tmean is required for the subsequent epidemiological analysis (but aggregated to spatial boundaries)

```
ds_daily_tasmean_17_22July2024 = ds.resample(time='D').mean()
ds_daily_tasmean_17_22July2024

<xarray.Dataset>
Dimensions:    (latitude: 721, longitude: 1440, time: 7)
Coordinates:
  * latitude   (latitude) float64 90.0 89.75 89.5 89.25 ... -89.5 -
89.75 -90.0
  * longitude  (longitude) float64 -180.0 -179.8 -179.5 ... 179.2
179.5 179.8
  * time       (time) datetime64[ns] 2024-07-17 2024-07-18 ... 2024-
07-23
Data variables:
    t2m        (time, latitude, longitude) float32 0.5374 0.5374 ... -
37.21
Attributes:
    GRIB_edition:            2
    GRIB_centre:             ecmf
```

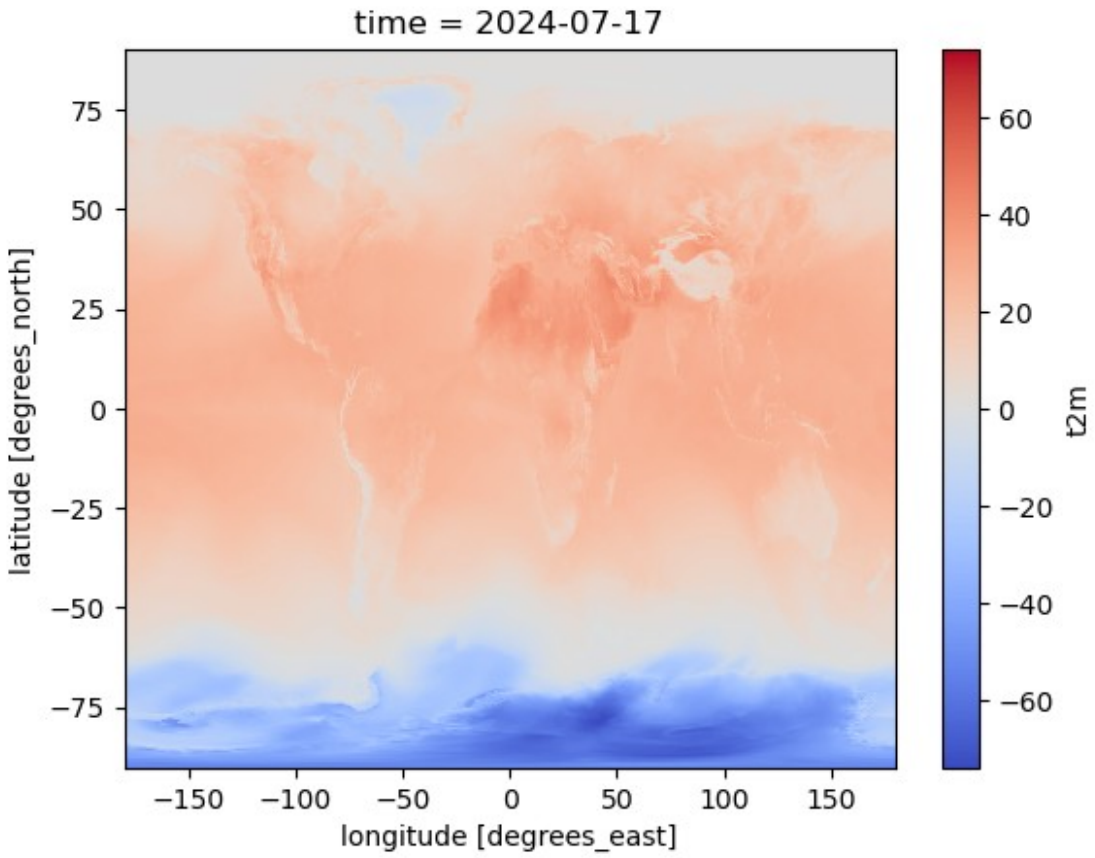
```
    GRIB_centreDescription:  European Centre for Medium-Range Weather
Forecasts
    GRIB_subCentre:          0
    Conventions:             CF-1.7
    institution:             European Centre for Medium-Range Weather
Forecasts
    history:                 2024-07-18T11:37 GRIB to CDM+CF via
cfgrib-0.9.1...
```

Some more demo plots, this time using daily Tmean

```
ds_daily_tasmean_17_22July2024.t2m.sel(longitude = -0.31, latitude =
51.41, method='nearest').plot()
plt.title("ECMWF - mean 2m temperature [deg C] forecast for Kingston
Upon Thames on July 17-22, 2024")

Text(0.5, 1.0, 'ECMWF - mean 2m temperature [deg C] forecast for
Kingston Upon Thames on July 17-22, 2024')
```




```
ds_daily_tasmean_17_22July2024.t2m[0].plot(cmap=plt.cm.coolwarm)

<matplotlib.collections.QuadMesh at 0x1990ba750>
```



Save as daily 0.25 deg gridded mean temperature (Tmean) as a netcdf file which can then be read in R or Python along with the geographic boundaries (shape files) for spatially aggregating the Tmean.

```
ds_daily_tasmean_17_22July2024.to_netcdf(path="tas_daily_17_July_22July_2024.nc", mode='w')
```